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Compact Dual-Band Antenna with High Gain and Simple Geometry for 5G Cellular Communication Operating at 28 GHz and 44 GHz

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Abstract

This work elaborates a dual-band antenna which finds its applications in mobile and satellite communication systems within the context of 5th generation (5G) technologies. The proposed antenna is designed by using semi-flexible substrate material Roger/RT duroid 5880 with an overall dimension of 15 mm × 15 mm × 0.79 mm. The antenna structure is composed of dual circular patches along with elliptical patch, which is further loaded with two elliptical slots. The proposed antenna has the capability to operate from 25.8 - 29.9 GHz and 41.8 - 52GHz with central frequencies at 28 GHz and 44 GHz used for mobile and satellite communications, respectively. The proposed propagation device includes various advantages including its compact size with low geometric complexity, high gain and wide operational bandwidths which makes it good potential candidate for mm-wave applications and 5G communication systems.

1 Introduction

The expeditious technological advancements were observed in mobile and wireless technologies from 1st generation to 5th generation (5G). Currently, majority of development is on exploiting 5G technologies, with swift focus on developing 6G technologies having characteristics of devices with smaller size, high efficiency, and enhanced performance [1]. Furthermore, the requirements for optimal operation of communication system commensurate with variations of new technologies like Long Term Evolution (LTE), Internet of Things (IoT) and others [2]. Thus, the modern communication systems require the antennas and propagation devices having characteristics of compact size, high gains, optimal directivity, wide band operation and enhanced efficiency to handle large throughput of data [3].

By considering aforementioned challenges and necessities of various state-of-the-art systems, researcher proposed various antennas for 5G and mm-wave applications [4]-[13]. In addition, multiband antenna having desired frequency response remains a valuable approach in every generation of wireless communication as it mitigates the need of multiple antennas; therefore, resulting in compact and cost-effectiveness in the design model. A tri-band antenna for satellite communication is proposed in [4] but the design has relatively narrow bandwidth as in 5G wideband are key requirement. A triangular shaped patch was proposed in [5] for 43.9, 61.8, 75.8, and 94 GHz applications, although the antenna show satisfactory performance, but the radiation pattern was distorted and consequently limited its application. A dual band antenna to operate at 28/38 GHz is presented in [6]. The presented antenna had drawbacks as it is structurally complex with its multilayer structure and has undesired frequency response due to its limited bandwidths. A frequency reconfigurable antenna was presented in [7] having compact size and high gain; however, its narrow bandwidth limits its applications. In [8] another dual band antenna 28/38GHz was presented and further utilized to design eight element arrays to improve gain of antenna at the cost of structural complexity and substantial size. Another simple and compact dual band antenna was presented in [9] having advantage of high gain. On the contrary, it has setbacks of bigger dimension and narrow bandwidth. In [10] and [11] triband antennas were proposed for mm-wave communication systems. The antenna presented in [10] offers high gain at the cost of structural complexity and relatively large dimension. While the antenna presented in [11] offers compact size and moderate gain, its frequency band offers narrow coverage. A patch antenna array for satellite communication was presented in [12]. Although the antenna operates on multiple frequencies of 15.3, 23.23, and 31.68 GHz, however due to the extensive usage of array, the antenna limits its application for compact size devices. A dual band antenna for 5th generation handset applications and satellite communication has presented in [13]. The unit element offers low gain and narrow bandwidth. Even though the array offers a moderate bandwidth and high gain, it is fairly limited in its applications having the setbacks of structural complexity due to Defected Ground Structure (DGS) and large dimension.

Keeping the considerations, requirements and limitations of 5G and mm-wave antennas, a compact dual-band antenna is presented in this paper. The antenna structure is composed of dual circular patches along with elliptical patch, which is further loaded with two elliptical slots. The antenna offers various advantages including compact size, low geometrical complexity, operation in two frequency bands and high gain which makes it a potential candidate for compact mm-wave and 5G communication systems.

2 Antenna Design and Methodology

The proposed antenna was embedded on the top side of Roger/RT Duriod 5880 having the relative permittivity of 2.2 and loss tangent of 0.0009, as shown in Fig.1(a). The overall dimensions of the proposed antenna are 15mm × 15mm × 0.79mm ($A_Y \times A_X \times H$). The rear side of the antenna was covered by copper which acts as a ground plane for the propagating element, as depicted in Fig.1(b). The dimensions of the various parameters of the proposed antenna are as follow: $F_Y = 0.4$ *mm;* $F_X = 4.25$ *mm;* $R_1 = 0.75$ *mm;* $R_2 = 1.4$ *mm;* $R_3 = 4$ *mm;* $R_4 = 5.5$ *mm.*

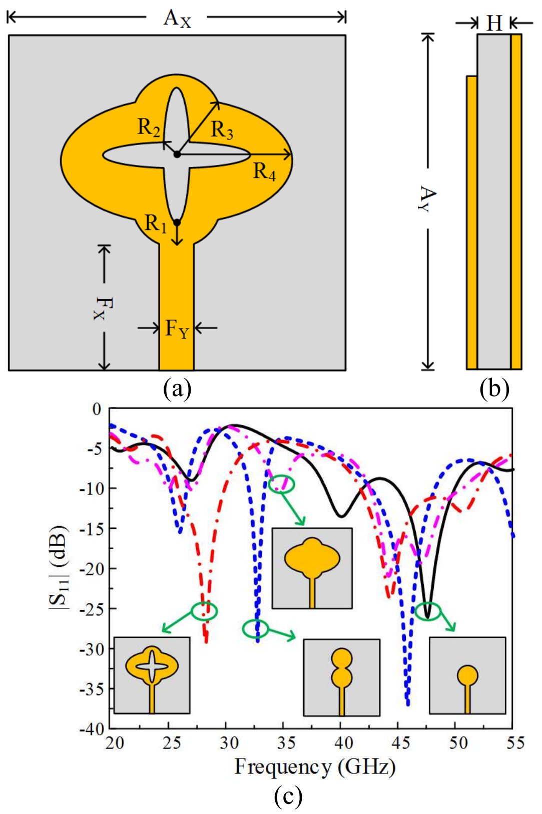


Figure 1. Geometerical configuration of proposed antenna, (a) top-view, (b) side-view**.** (c) Various antenna design steps and corresponding reflection coefficients graphs.

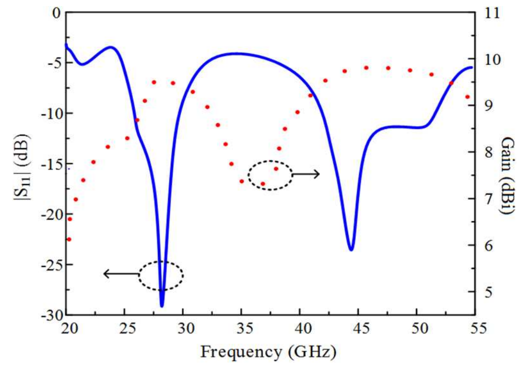
A number of steps and design methodologies involved in designing of the proposed antenna and their corresponding $|S_{11}|$ results are depicted in Fig.1(c). Initially, a circular patch antenna was designed for satellite communication. The radius of the antenna can be estimated by using the equations provided in [14]. The resultant antenna resonates at 47.5 GHz having an impedance bandwidth ranging 45 – 50.15 GHz, as depicted in Fig.1(c). Furthermore, a fractal patch was utilized to further shift the frequency toward the lower bands, a detail discussion on the principle of shifting frequency by using fractal patches were presented in [15]. By loading a fractal patch, the resultant antenna starts resonating at three frequencies of 27 GHz, 33 GHz, and 45.8 GHz, as depicted in Fig.1(c). However, it could be observed that the operational bandwidth of resonating frequencies become narrow. Thus, to improve the impedance bandwidth of the antenna, an elliptical shaped patch was inserted. The antenna resonates at 44.5 GHz having a wide impedance bandwidth ($|S_{11}| < -10$dB) of 9.8 GHz ranging from 42.4 GHz to 52.2 GHz. On the other hand, it was observed that return loss significantly increases at the lower resonance around 27 GHz, as depicted in Fig.1(c). Hence, in order to improve the reflection coefficient at the desire lower frequency of 28 GHz, a pair of orthogonal elliptical slots were etched from the center of radiator. The internal radius and aspect ratio of the slots were to optimize to get the best possible results. The final antenna exhibits dual-band at 28.2 GHz and 44 GHz having impedance bandwidth ($|S_{11}|<-10$dB) of 5.3 GHz (25.9 – 31.2 GHz) and 10.5 GHz (41.8 – 52.3 GHz), respectively. The final antenna was further optimized using parametric analysis to achieve best possible results.

3 Results and Discussion

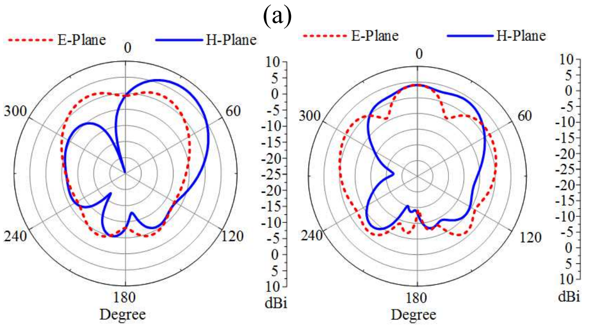
The numerical analysis of the proposed work was performed using electromagnetic solver Higher Frequency Structural Simulator (HFSS) using an appropriate radiation boundary. Various performance parameters of the antenna including scattering parameter, gain and radiation pattern was discussed in this section to show the performance analysis of the work.

Fig.2(a) presents the reflection coefficient and gain of the proposed antenna. The final design of the antenna exhibits dual-mode operation having the central frequency of 28 GHz and 44 GHz. The antenna offers an impedance bandwidth ($|S_{11}|<-10$dB) of 5.5 GHz (25.75 – 31.25 GHz) at lower pass-band covering an entire bandwidth allocated for 28 GHz global cellular communication (26.5 – 29.5 GHz). Additionally, a wide bandwidth of 10.9 GHz (41.5 – 52.4 GHz) was observed for upper pass-band that covers the majority portion of V-band, widely used for satellite communication, radar and tracking applications.

Fig.2(a) also presents the peak gain of the antenna, it could be observed that antenna exhibits a high gain of > 7.8 dBi in both pass-bands. However for the frequency bands where $|S_{11}|>-10$dB, a decrement in gain is observed which is infact due to increase in return loss.



(a)



(b) (c)

(c)

Figure 2. (a) Reflection coefficient and the peak gain of the proposed antenna. Radiation pattern of proposed dual-band antenna in E- and H-planes at operational frequencies of, (b) 28 GHz and (c) 45 GHz.

The radiation patterns of the proposed antenna at central frequency was presented in Figs.2 (b) and (c). The antenna exhibits a broadsight radiation pattern in principle E-plane ($\Phi = 0^0$) while a slightly titled radiation pattern was observed in principle H-plane ($\Phi = 90^0$) for 28 GHz, as depicted in Fig.2(b). On the other hand, at 45 GHz the antenna exhibits broadsight radiation pattern in both E- and H-planes, as depicted in Fig.2(c).

Table.1 presents the comparison of the proposed work with state-of-the-art. Although, most of the antennas offer compact size as compared to the proposed work but they have set back including narrow bandwidth and low gain. Thus, the proposed dual-band antenna offers a good combination of compact size, wide bandwidth, and radiation gain in comparison to the existing works.

Table 1. Comparison of proposed work with literature.

References	Dimension (mm^2)	Operating Frequencies (GHz)	Bandwidth (GHz)	Gain (dBi)
[4]	6.2 × 7.25	24, 35, 71	1.3, 3.5, 4	4.4, 3.6, 5.6
[5]	10.5 × 7.9	28, 60	1.69, 5.63	7.7, 7.4
[6]	5 × 5	28, 38	4.78, 4.16	6, 6.5
[7]	7 × 7	25, 50	0.44, 1.32	6.7, 8.1
[8]	16 × 16	28, 38	No Info	15.6, 10
[9]	19 × 19	10, 28	0.27, 1.02	5.5, 8
[10]	10 × 5	45, 57, 66	No Info	No Info
[11]	3.4 × 4.127	24, 28, 38	0.5, 1, 0.5	6.6,7,5
[12]	20 × 20	15, 23, 32	1.9, 2.8, 3.7	4, 3.9, 6.8
[13]	25 × 15	38, 60	1.3, 2.4	6.5, 5.5
This work	**15 × 15**	**28, 44**	**5.5, 10.9**	**8.6, 9**

4 Conclusion

A compact dual-band antenna for 5G and mm-wave communication system with relatively larger bandwidth coverage is investigated in this research article. The antenna was designed by using two circular patches along with an elliptical shape patch. To further improve the performance of the antenna a combination of orthogonal elliptical slot was etched from the patch. The resultant antenna offers dual-band at 28 GHz and 44 GHz having impedance bandwidths of 5.5 GHz and 10.9 GHz, respectively. The gain offered by the proposed antenna is more than 7.8 dBi in both pass-bands. Moreover, the comparison with state-of-the-art states that the proposed work becomes a potential candidate for 5G cellular communication and V-band applications.

5. Acknowledgments

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